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ANALYSIS OF THE AERODYNAMIC CHARACTERISTICS OF DEVICES FOR INCREASING WING LIFT. III. INFLUENCE OF GROUND PROXIMITY ON THE AERODYNAMIC CHARACTERISTICS OF THE FLAPS

Rafael Garncarek

Translation of"Analiza charakterystyk aerodynamiczych urzadzen zwiekszajacych sile nosna skrzydla, Czesc 3, Wplyw bliskosci ziemi na charakterystyke aerodynamiczna klap," Technika Lotnicza i Astronautyczna, Vol. 28, June 1973, pp. 21, 22 & 29

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16. Abstract
The thrid part of the article discusses the effect of ground proximity on the aerodynamic characteristics of flaps. Diagrams are presented which can be used to plot the aerodynamic characteristic of the aircraft taking into account the proximity of the ground. The conclusions based on the discussion are presented at the end of the article.

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ANALYSIS OF THE AERODYNAMIC CHARACTERISTICS OF DEVICES FOR INCREASING WING LIFT. III. INFLUENCE OF GROUND PROXIMITY ON THE AERODYNAMIC CHARACTERISTICS OF THE FLAPS

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As the wing approaches the ground, changes occur in the flow around its profile. An increase in the above-gage atmospheric pressure occurs on the lower surface of the wing as a result of the ground effect. On its upper surface, the below-gage atmospheric pressure increases near the leading edge and drops somewhat near the trailing edge. The net result is an increase in the aerodynamic lift for a given angle of attack and a decrease in the angle of attack corresponding to zero aerodynamic lift. The change in the pressure distribution on the upper surface of the wing causes, in agreement with boundary layer theory, a decrease in the critical angle of attack α_{cr} at which flow separation occurs. Hence the value $C_{z\,max}$ decreases. The proximity of the ground decreases the deflection angle behind the wing and thus also the drag induced by a wing of finite span. /21* /22

In the case of a low tail plane, the effect of the ground may unfavorably decrease, through a decrease of the deflection angle of the flow behind the wing and the ground effect, the downward force which is needed to maintain the airplane in equilibrium at large angles of attack. In the case of an airplane which attains on the ground angles of attack that are close to the stalling angle, the effect of ground proximity will reduce the takeoff and landing speed, increasing C_z for the given angle of attack.

Figures 22-25 show the effect of ground proximity on $C_{z\,max}$, $C_{x\,ind}$, α_0 and $dC_z/d\alpha$.

*Numbers in the margin indicate pagination in the foreign text.

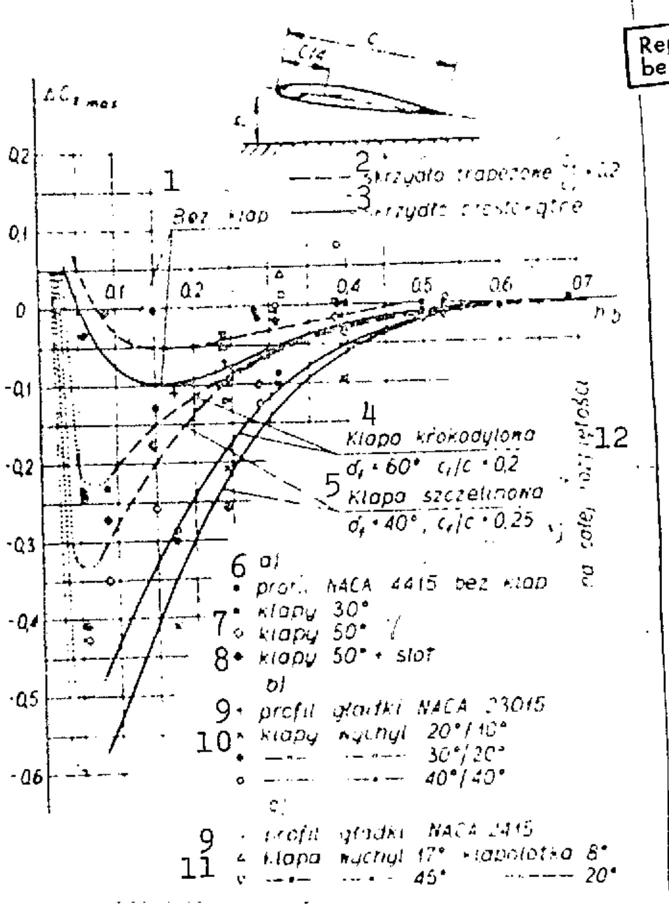


Fig. 22. Effect of ground proximity on $C_{z_{max}}$.

a) Wing span A = 10(C_f/C_r) = 0.3 Technical Note NACA 4415 two-slotted flap 0.5c + slat 0.214c Re = $0.45 \cdot 10^6$

b) NACA 23015 profile, A = 4.55 double flap (0.40/0.256)c on entire span + slat 0.184c; rectangular airfoil, Re = $0.72 \cdot 10^4$ In accordance with Report No. 14/TA/66, "Study of the effect of ground proximity on the aerodynamic characteristic of airfoil with 40% two-slotted flap and slat.

c) Flap and aileron flap 0.28c flap 0.457b, aileron flap 0.368b, rectangular airfoil together with fuselage A = 7.95, Re = $0.55 \cdot 10^6$. In accordance with Report No. 21/ /TA/66, "Studies of ground effect on the aerodynamic characteristics of the model PZL-104 Wilga airplane.

Key to Fig. 22 on following page.

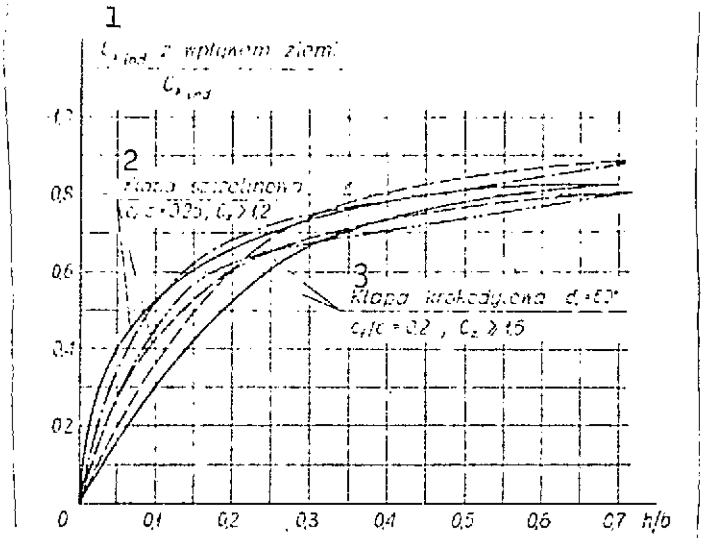
Figure 22 compares the average decrease in $C_{z_{max}}$ resulting from the ground effect with the values that were obtained from models tested in wind tunnels. The results of the airfoil studies confirm approximately the curves for the average values.

Figure 26 shows the variation in moment ratio of the inclined wing. As was to be expected, the changes in the pressure distribution along the chord cause a drop in the increase in the pitching moment from the flaps as the wing approaches the ground.

Figures 22-26 can be used to estimate the aerodynamic characteristics of an aircraft, taking into account the

Key to Fig. 22:

1. Without flaps
2. Tapered wing
3. Rectangular wing
4. Split flap
5. Slotted flap
6. Airfoil section without flaps
7. Flaps
8. Flaps + slat
9. Smooth NACA ... airfoil section
10. Displaced flaps
11. Flap displaced ..., aileron flap ...
12. Over entire span



----- tapered wing $C_t/C_r = 0.2$
——— rectangular wing
—·· — tapered wing $C_t/C_r = 0.2$
—·— rectangular wing

Fig. 23. Effect of ground proximity on drag induced by wing.

Key: 1. $C_{x_{ind}}$ vs. ground effect
2. Slotted flap
3. Split flap

effect of ground proximity. The effect of the ground proximity on the downwash behind a wing with a displaced flap can be described by the following approximate formula:

$$\varepsilon_z \approx \sqrt{\frac{z_k}{b}}\left(\frac{2C_z}{\pi\Lambda}\cdot K_1\cdot K_2+\frac{0.55}{\Lambda_k}\cdot\Delta C_{z_k}\right)$$

where

$\frac{2C_z}{\pi\Lambda}\cdot K_1\cdot K_2$ is the downwash behind a wing with a retracted flap;

$\frac{0.55}{\Lambda k}\Delta C_{z_k}$ is the increment in the downwash due to flap displacement; ΔC_{z_k} is the increment in the lift coefficient due to flap displacement; Λk is the aspect ratio for the flap span part of the wing; z_k is the distance from the trailing edge of the flaps to the ground; and b is the wingspan.

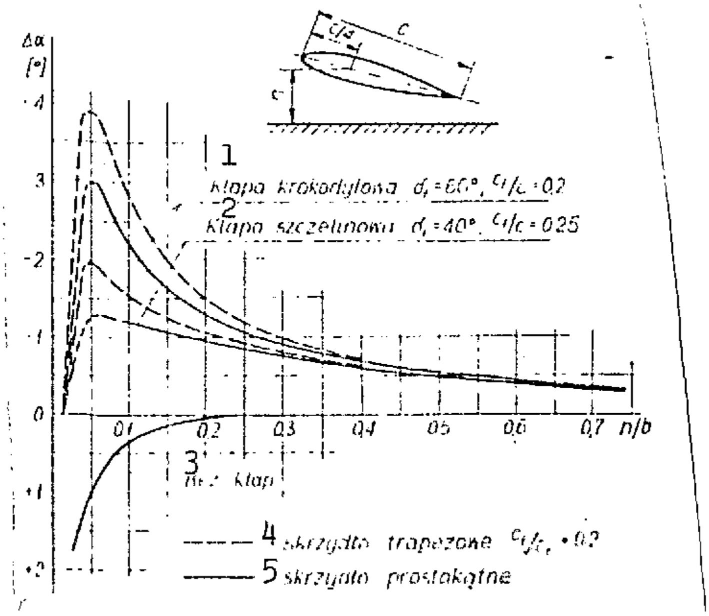


Fig. 24. Effect of ground proximity on α_o.

Key: 1. Split flap
2. Slotted flap
3. Without flaps
4. Tapered wing
5. Rectangular wing

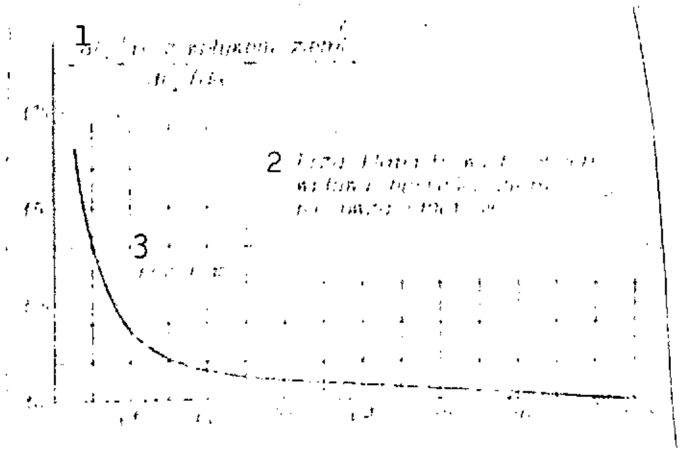


Fig. 25. Effect of ground proximity on the slope of the $C_z = f(\alpha)$ curve.

Key: 1. Vs. ground effect
2. The effect of ground proximity is not taken into account for displaced flaps
3. Without flaps

The formula is valid for $z_k < b$.

Conclusions

As a result of the above discussion, the following conclusions can be made.

1. The increment in the magnitude of the maximum lift coefficient $\Delta C_{z_{max}}$ for a given type of flap with a particular geometry is mainly determined by the thickness of the airfoil section. The effect of the thickness of the airfoil section is greatest for split flaps and smallest for single-slotted flaps.

2. In the range of airfoil section thicknesses from 14% and above, instead of the much more complicated double flaps, the much simpler two-slotted flaps can be used.

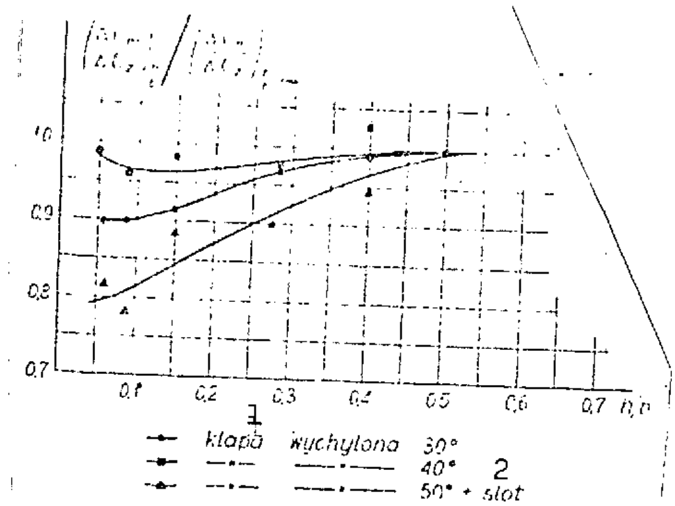


Fig. 26. Change in the $\Delta C_m/\Delta C_z$ ratio due to a displacement of a two-slotted 0.5c flap as a result of the effect of ground proximity at a constant angle of attack $\alpha = \alpha_{C_z=0} + 6°$.

Key: 1. Flap displacement
2. Slat

3. In the range of airfoil section thicknesses from 8% to 12%, in view of the difficulty of placing a slat with the appropriate geometry in a thin airfoil section, the two-slotted flap is no longer effective, and depending on the required value of $\Delta C_{z_{max}}$, either a single-slotted or double flap should be used.

4. In the case when we desire a small increment in the aerodynamic lift with a minimum increase in the drag (for small displacements), the best solution is to use a straight flap with a chord on the order of 0.2-0.3 of the wing chord. The efficiency of a straight flap decreases very little when flow which equalizes the pressure on the lower and upper surfaces of the wing can pass through the slot between the flap and the torque box of the wing. /29

5. When the aerodynamic characteristic of an aircraft with displaced flaps is estimated, the assumption can be made -- without making a large error -- that the increment $\Delta C_{z_{max}}$ is independent of the Reynolds number.

6. The increment in the profile drag resulting from a small displacement of a slotted flap (on the order of 20°)

with a basic laminar airfoil section and sufficiently large angle of attack (above the range of angles corresponding to the characteristic dip in the polar curve of the airfoil in the direction of small drags) is negligibly small.

7. When the aircraft equilibrium during takeoff and landing is calculated, as well as the takeoff and touch-down speed and the length of the takeoff run and landing run, one should use the aerodynamic characteristic of the aircraft which takes into account the effect of ground proximity.

The proximity of the ground changes the pitching moment, the aerodynamic lift, the drag induced by the wing, and the tailplane. This effect is particularly pronounced in low-wing monoplanes and in aircraft with a low tailplane.